# VANADIUM RAILS

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A REPORT OF TESTS OF VANADIUM STEEL RAILS WITH COMPARATIVE TESTS WITH SIMPLE CARBON STEEL RAILS OF THE SAME SECTION AND MANUFACTURE

1914

AMERICAN VANADIUM COMPANY

VANADIUM BUILDING, PITTSBURGH, PA.

# VANADIUM RAILS

Convinced from results along other lines that the use of vanadium in rail steel will greatly reduce rail failures and at the same time greatly increase the wearing quality of the rails, the American Vanadium Company has had several heats of basic open hearth vanadium steel rolled into rails for test purposes.

While no question exists as to the beneficial effects of vanadium in steel, the price until the past year has been too high to make it commercially practicable to use it in RAILS.

It is universally recognized that the rail situation is one of the most serious confronting the railroad officials today.

Considerations, primarily of safety, and also of economy, urgently demand a decided improvement in the quality of rail steel.

The tonnage of rails for replacement purposes has greatly increased. Published estimates from the statistics available place this increase at 50 per cent. over that of a few years ago, or an increase from 1,000,000 tons annually to fully 1,500,000 tons.

The railroads and rail makers have tried to meet the situation by increasing the weight of the rail section. At the same time harder, higher carbon steels have been used in the effort to obtain increased strength and wearing qualities; until now rails are rolled from practically spring steel, or low grade tool steel.

The result, although attended with some degree of success, has failed to lessen rail breakage. On the contrary, the use of high carbon steel has introduced new causes of failure; namely, internal fissures, commonly known as "silvery oval spots".

It is evident that a steel of greater strength, toughness and better wearing qualities, together with greater homogeneity and freedom from segregation, than simple carbon steel, is required to meet the situation.

Through the addition of a small percentage of vanadium to simple carbon standard rail steel, rails of exceptionally great strength, toughness and wearing qualites are obtained. This is shown by the tests given in the following pages in which comparison is also made with corresponding tests from simple carbon steel rails of the same section rolled at the same time by the same mill.

Briefly summarized, the salient facts as shown by analysis of the results of the tests are as follows:

## SUMMARY

Manufacture: The manufacture of rails from vanadium steel does not require any change in the usual rail mill practice. The steel rolls clean and shows no tendency to crack or tear. No change is necessary in the gauges; as vanadium steel takes the same standard gauge as simple carbon steel. Nothing developed in the melting, casting, heating or rolling of these heats of vanadium steel to indicate that the mill output will in any way be reduced. The percentage of yield of rails from the ingots is equal to or even greater than for simple carbon steel rails; and the evidence is that there will be less scrap from cracking or tearing in the rolls, and also that the percentage of second quality rails will be less.

Drop Tests: The vanadium steel rails met all the requirements specified for ductility and deflection and are stiffer or more resilient than the 100-lb. carbon steel rails of the same section, with which they were compared. The vanadium steel rails deflected about the same amount from an 18-ft. blow as the carbon steel rails did from a 15-ft. blow.

Tensile Tests: The vanadium steel rails show an elastic limit, or useful strength averaging, over 40% higher than for the simple carbon steel rails; though the latter had 50% higher carbon content. The ratio of elastic limit to tensile or breaking strength is 70% or more for the vanadium steel rails as compared with about

57% for the carbon steel rails. The ductility or toughness of the vanadium steel rails also shows higher than for the carbon steel rails. These tests are a direct measurement of the superiority of the vanadium over the carbon steel rails.

Alternating Impact Tests: These tests prove that vanadium steel of the high elastic limit shown by these rails has great endurance under repeated stresses and is free from brittleness.

Bend Tests: Although the vanadium steel rails are very much harder than the simple carbon steel rails with which they are compared, the bend tests are equally as good.

Hardness Tests: The vanadium steel rails show great uniformity of hardness throughout the entire section; and are from 10% to 35% harder than the carbon steel rails of 50% higher percentage of carbon. This superior hardness, combined with the high elastic limit and the great toughness of the vanadium steel rails indicate a great increase in wear resisting qualities.

Wear Tests: Comparative tests to determine resistance to wear show a very great increase in wear resisting qualities for the vanadium over the simple carbon steel rails.

Chemical Uniformity (Segregation): The vanadium steel rails show no segregation, the variations in analysis noted being within the allowable limits of analytical error. The standard high carbon steel rails usually show segregation and in the case of the "A" rails the segregation is frequently very marked.

Homogeneity and Density: Sections from the vanadium steel rails etched with boiling dilute sulphuric acid show a remarkably dense, uniform structure, free from piping, slag and other defects. The contrast in this respect with the etched sections of the carbon steel rails, as shown in the accompanying reproductions of photographs, is very striking. The carbon rails were selected at random by the makers.

VANADIUM STEEL HEAT 26813, RAIL "A"

Shows only a slight amount of piping at the top of the web and in the web. The appearance of the center of the head of this etched section would indicate that the center of the top of the ingot was a little soft or green when bloomed. A few of the ingots from this heat were heavily cropped at the bloom shears on this account.

VANADIUM STEEL HEAT 26813, RAIL "B"
Shows a very solid, uniform, dense structure.

VANADIUM STEEL HEAT 27989, RAIL "A"
**Shows a perfectly uniform, dense structure with no evidence of residual piping.**

VANADIUM STEEL HEAT 27993, RAIL "A"
Shows a uniform, dense structure, with only the very slightest indication of residual piping

CARBON STEEL, RAIL "A"
Is typical of most "A" rail structures and is really better than many; because more than the usual discard was made from the top of the ingots in rolling this lot of rails

CARBON STEEL, RAIL "B"
Shows residual piping, quite marked on the left side of the etching

Three heats of vanadium steel were made to the following chemical specifications:

| | Heat 26813 | Heat 27989 | Heat 27993 |
|---|---|---|---|
| Carbon | .45 to .65% | .40 to .52% | .60 to .75% |
| Manganese | 1.10 to 1.40% | 1.00 to 1.30% | .75 to 1.00% |
| Silicon | under .20% | under .20% | under .20% |
| Phosphorus | under .05% | under .05% | under .05% |
| Sulphur | under .05% | under .05% | under .05% |
| Vanadium | 4 lbs. to ton | 4 lbs. to ton | 4 lbs. to ton |

In the first two heats, the manganese specified is higher than usual; as previous investigations have shown that with manganese somewhat higher than usual the effect of the vanadium on the physical properties of the steel is still further increased. The third heat, however, conforms to the usual specification for rail steel.

The actual chemical compositions of these three heats are:

| | Heat 26813 | Heat 27989 | Heat 27993 |
|---|---|---|---|
| Carbon | .550% | .510% | .558% |
| Manganese | 1.510% | 1.110% | .780% |
| Silicon | .170% | .120% | .158% |
| Phosphorus | .015% | .010% | .017% |
| Sulphur | .019% | .029% | .025% |
| Vanadium | .148% | .146% | .156% |
| Actual per cent. Vanadium added | .168% | .160% | .177% |

Heat 26813—The manganese is higher than called for, due to the percentage of loss in manganese addition not being nearly as great as allowed for in usual practice.

Heat 27993—The percentage of carbon is about 5 points below the limit called for, due to various mill delays.

## PRODUCTION

The production percentage, or yield of rails per ton of ingots, is higher than usual; although from the evidence of the tests which follow it seems as though it might be possible to obtain even higher yields.

| | | | |
|---|---|---|---|
| Date | 4-22-14 | 7-27-14 | 7-27-14 |
| Heat | 26813 | 27989 | 27993 |
| Ingots, weight | 121,000 lbs. | 104,400 lbs. | 108,000 lbs. |
| Rails, weight | 89,500 lbs. | 80,200 lbs. | 82,000 lbs. |
| Rails, number | 77-1st, 5-2nd | 73-1st, 1-2nd | 73-1st, 2-2nd |
| Rails, scrap | none | none | none |
| Per cent. yield | 74.0 | 76.9 | 75.9 |

All three vanadium steel heats rolled perfectly. The blooms were clean and free from seams and cracks, and no scrap rails were produced. The standard gauges were used; showing that the shrinkage of the steel is the same as for standard carbon steel, and that no change in this respect is necessary. Nothing developed in the heating and rolling to indicate that the mill output would be in any way reduced by the use of vanadium steel. The top portion of some of the ingots from the first heat, 26813, were a little soft or green when bloomed, and were cropped heavily on this account.

## DROP TESTS

When the first heat, 26813, was made, it was arranged to make drop tests on crop ends from both the "A" and "B" rail of three ingots, representing the beginning, middle and end of the pouring. Through misunderstanding, this was not carried out on the second heat, 27989; and only three drop tests were made from this heat, one being from a "C" rail crop; as the top blooms from the ingots were rolled into 3-rail lengths. The arrangement for two drop tests from the beginning, middle and end of the third heat, 27993, was carried out, excepting that the tests were made on "C" rail crops instead of "B" rail; on account of the top blooms all having been rolled into 3-rail lengths.

The usual requirements for drop test were followed, excepting that the height of the drop was increased from 15 ft. to 18 ft. for the vanadium rails. Two vanadium rails from the first heat, however, were tested with the height of the drop at 15 ft.; in order to get a direct comparison with the carbon steel rails. One vanadium rail was tested with the flange up. All the others were tested in the usual manner with the head up.

Six one-inch spaces were laid off on the bottom of the flange; in order to determine the ductility or stretch after each blow of the drop, the requirements being 5% or 5-100-inch stretch in two adjacent inch spaces.

As will be seen, the vanadium steel rails met all the requirements specified for ductility and deflection. At the same time, they show up stiffer under the drop test than the carbon steel rails.

The chemical specifications to which the carbon steel rails were made are:

| | |
|---|---|
| Carbon | .62 to .75% |
| Manganese | .60 to .90% |
| Silicon | Under .20% |
| Phosphorus | Under .04% |

# DROP TESTS

## VANADIUM RAILS

| Heat No. | Ingot No. | Rail | Height of Drop, Feet | No. of Blows | Deflection in Inches | Elongation in Hundredths of an Inch — Per Inch: 1 in. | 2 in. | 3 in. | 4 in. | 5 in. | 6 in. | Total | Fracture |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26813 | 16 | A | 15 | 1 | 0.7 | 4 | 3 | 5 | 4 | 4 | 2 | 22 | Clear |
| | | | | 2 | 1.4 | 5 | 6 | 8 | 7 | 7 | 5 | 38 | |
| | | | | 3 | 3.2 | 16 | | 19 | 17 | 17 | 14 | | |
| 26813 | 16 | B | 15 | 1 | 0.9 | 3 | 5 | 4 | 4 | 3 | 3 | 22 | Clear |
| | | | | 2 | 1.6 | 6 | 9 | 8 | 7 | 4 | 4 | 38 | |
| | | | | 3 | 2.3 | 8 | 12 | 12 | 10 | 6 | 5 | 53 | |
| | | | | 4 | 2.9 | 13 | 16 | 14 | 10 | 6 | 5 | 64 | |
| | | | | 5 | 3.7 | 17 | 23 | 20 | 14 | 8 | 6 | 88 | |
| | | | | 6 | 4.6 | 18 | | 19 | 13 | 8 | 6 | | |
| 26813 | 1 | A | 18 Flange Up | 1 | 1.0 | 5 | 6 | 7 | 6 | 5 | 3 | 32 | Clear |
| | | | | 2 | 1.7 | 6 | 7 | 9 | 8 | | 3 | | |
| 26813 | 1 | B | 18 | 1 | 1.1 | 4 | 6 | 6 | 4 | 3 | 3 | 26 | Clear |
| | | | | 2 | 1.8 | 8 | 9 | 9 | 6 | 4 | 4 | 40 | |
| | | | | 3 | 2.7 | 12 | 14 | 11 | 8 | 4 | 4 | 53 | |
| | | | | 4 | 3.6 | 15 | 16 | 14 | 10 | 7 | 5 | 67 | |
| | | | | 5 | 3.7 | 16 | | 14 | 10 | 6 | 4 | | |
| 26813 | 9 | A | 18 | 1 | 1.0 | 4 | 4 | 5 | 5 | 4 | 2 | 24 | |
| | | | | 2 | 1.8 | 4 | 4 | 5 | | 5 | 3 | | *Web Piped |
| 26813 | 9 | B | 18 | 1 | 1.0 | 3 | 4 | 5 | 5 | 5 | 4 | 26 | Clear |
| | | | | 2 | 1.8 | 5 | 6 | 8 | 8 | 8 | 5 | 40 | |
| | | | | 3 | 2.6 | 6 | 8 | | | 10 | 7 | | |
| 27989 | 1 | A | 18 | 1 | 1.0 | 3 | 4 | 5 | 5 | 4 | 2 | 23 | Clear |
| | | | | 2 | 1.9 | 4 | 5 | 7 | 10 | 10 | 9 | 45 | |
| | | | | 3 | | 5 | 8 | 11 | 11 | 11 | 9 | 55 | |
| 27989 | 6 | C | 18 | 1 | 1.1 | 3 | 4 | 5 | 5 | 5 | 5 | 27 | Clear |
| | | | | 2 | 2.1 | 5 | 5 | 7 | 10 | 10 | 9 | 46 | |
| | | | | 3 | | 7 | 8 | 12 | 13 | 12 | 10 | 62 | |
| 27989 | 14 | A | 18 | 1 | 1.1 | 2 | 3 | 5 | 5 | 5 | 5 | 25 | Clear |
| | | | | 2 | 2.0 | 5 | 7 | 10 | 10 | 8 | 6 | 46 | |
| | | | | 3 | | 7 | 11 | 16 | 15 | 13 | 10 | 72 | |
| 27993 | 1 | A | 18 | 1 | 1.0 | 3 | 3 | 4 | 4 | 4 | 4 | 22 | Clear |
| | | | | 2 | 1.9 | 4 | 6 | 7 | 8 | 8 | 7 | 40 | |
| | | | | 3 | | 7 | 7 | 9 | 9 | 10 | 8 | 50 | |
| 27993 | 1 | C | 18 | 1 | 1.1 | 3 | 4 | 5 | 5 | 5 | 4 | 26 | Clear |
| | | | | 2 | | 4 | 5 | 7 | 9 | 8 | 8 | 41 | |
| 27993 | 6 | A | 18 | 1 | 1.1 | 2 | 3 | 4 | 5 | 5 | 5 | 24 | Clear |
| | | | | 2 | | 3 | 4 | 5 | 7 | 7 | 7 | 33 | |

## DROP TESTS—Continued

### VANADIUM RAILS

| Heat No. | Ingot No. | Rail | Height of Drop, Feet | No. of Blows | Deflection in Inches | Elongation in Hundredths of an Inch — Per Inch — 1 in. | 2 in. | 3 in. | 4 in. | 5 in. | 6 in. | Total | Fracture |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27993 | 6 | C | 18 | 1 | 1.1 | 3 | 4 | 5 | 5 | 4 | 3 | 24 | Clear |
| | | | | 2 | 2.0 | 6 | 8 | 9 | 9 | 8 | 6 | 46 | |
| | | | | 3 | | 7 | 8 | 11 | 10 | 10 | 8 | 54 | |
| 27993 | 14 | A | 18 | 1 | 1.2 | 4 | 5 | 5 | 5 | 5 | 4 | 28 | Clear |
| | | | | 2 | 2.2 | 6 | 7 | 9 | 8 | 8 | 8 | 46 | |
| | | | | 3 | 3.2 | 8 | 9 | 11 | 10 | 10 | 12 | 60 | |
| | | | | 4 | | 8 | 9 | 11 | 12 | 13 | 14 | 67 | |
| 27993 | 14 | C | 18 | 1 | 1.1 | 3 | 4 | 4 | 5 | 5 | 4 | 25 | Clear |
| | | | | 2 | 2.1 | 6 | 8 | 10 | 10 | 8 | 6 | 48 | |
| | | | | 3 | | 8 | 11 | 15 | 15 | 11 | 8 | 68 | |

### CARBON RAILS

| Test No. | Height of Drop, Feet | No. of Blows | Deflection in inches | Elongation in Hundredths of an inch — Per Inch — 1 in. | 2 in. | 3 in. | 4 in. | 5 in. | 6 in. | Total | Fracture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 15 | 1 | 1.0 | 3 | 4 | 4 | 3 | 3 | 3 | 20 | Clear |
| | | 2 | 1.9 | 5 | 6 | 7 | 7 | 7 | 5 | 37 | |
| | | 3 Nicked | | | | | | | | | |
| 2 | 15 | 1 | 1.0 | 4 | 4 | 4 | 3 | 3 | 2 | 20 | Clear |
| | | 2 | 1.8 | 5 | 6 | 7 | 7 | 6 | 5 | 36 | |
| | | 3 Nicked | | | | | | | | | |
| 3 | 15 | 1 | 1.1 | 4 | 4 | 5 | 5 | 4 | 3 | 25 | Clear |
| | | 2 Nicked | | | | | | | | | |

*A very small indication of piping which showed on one side only of the wedge-shaped piece broken out when the rail broke under the drop.

In addition to drop tests, one full length "A" rail from each of the three vanadium heats was broken into ten pieces and the fractures carefully examined for evidence of piping. Every fracture was found to be free from any evidence of piping.

## PHYSICAL TESTS

Tensile tests, alternating impact, and bend tests were made from rail crops from each heat, and also wear and hardness tests. The crops from the "A" rails were taken from the top end of the rail.

Tensile tests were also made from the middle section of each of the vanadium steel rails which were broken under the gag press. Corresponding tests for comparison were made from an "A" and "B" 100-lb. section carbon steel rail. These tests are shown in the following table; and the locations of the tests are indicated on the accompanying illustrations.

Due to the more rapid cooling of the rail crops, the tests from these show a little higher in elastic limit than the tests from the mid-section of the three rails broken in the gag press; as these rails cooled much more slowly on the hot bed.

## TENSILE TESTS

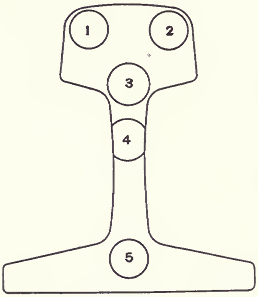


Fig. 1

**FIG. 1: Location of Tensile Tests Where 5 Tests Were Made.**

**FIG. 2: Location of Tensile Tests Where 8 Tests Were Made.**

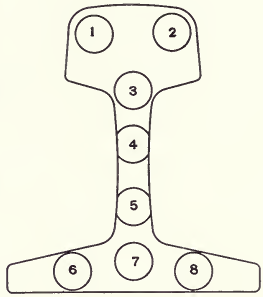


Fig. 2

### VANADIUM RAILS

| Heat No. | Rail | Test No. | Elastic Limit lbs. per sq. in. | Tensile Strength lbs. per sq. in. | Elongation in 2 in. per cent. | Reduction of Area per cent. |
|---|---|---|---|---|---|---|
| 26813 | A Crop | 1 | 130000 | 140000 | 12.0 | 22.0 |
| | | 2 | 102500 | 132500 | 5.0 | 5.5 |
| | | 3 | 100000 | 121000 | Broke in Fillet | |
| | | 4 | 107500 | 130000 | Broke in Fillet | |
| | | 5 | 105000 | 123000 | Broke in Fillet | |
| 26813 | A Rail (Mid Section) | 1 | 92600 | 130000 | 12.5 | 21.5 |
| | | 2 | 112000 | 135000 | 13.0 | 24.0 |
| | | 3 | 90000 | 125000 | 14.0 | 24.5 |
| | | 4 | 98000 | 130000 | 14.5 | 25.5 |
| | | 5 | 95000 | 129000 | 15.0 | 30.0 |
| | | 6 | 105000 | 137000 | 13.0 | 26.5 |
| | | 7 | 92000 | 128000 | 13.0 | 20.5 |
| | | 8 | 99000 | 134000 | 15.0 | 28.0 |
| 26813 | B Crop | 1 | 92000 | 134000 | 12.0 | 24.0 |
| | | 2 | 95000 | 133000 | 12.0 | 24.0 |
| | | 3 | 97500 | 125500 | 6.0 | 10.0 |
| | | 4 | 100000 | 126500 | Broke in Fillet | |
| | | 5 | 102500 | 140000 | 11.0 | 20.5 |

## TENSILE TESTS—Continued.

| Heat No. | Rail | Test No. | Elastic Limit lbs. per sq. in. | Tensile Strength lbs. per sq. in. | Elongation in 2 in. per cent. | Reduction of Area per cent. |
|---|---|---|---|---|---|---|
| | B | 6 | 105000 | 145000 | 10.5 | 25.5 |
| 26813 | Crop | 7 | 110000 | 147500 | 9.0 | 18.5 |
| | | 8 | 110000 | 147500 | 10.5 | 20.5 |
| | | 1 | 100000 | 130500 | 13.0 | 27.5 |
| | | 2 | 100000 | 133000 | 12.0 | 25.5 |
| | E | 3 | 102500 | 135000 | 11.0 | 20.5 |
| 26813 | Crop | 4 | 105500 | 142000 | 11.5 | 22.0 |
| | | 5 | 105000 | 140000 | 12.0 | 25.0 |
| | | 6 | 110000 | 140000 | 12.0 | 25.0 |
| | | 7 | 102500 | 135000 | 12.0 | 23.5 |
| | | 8 | 107000 | 140000 | 12.0 | 25.5 |
| | | 1 | 92000 | 127000 | 13.0 | 24.5 |
| | | 2 | 90000 | 127000 | 12.0 | 26.5 |
| | A | 3 | 98000 | 130500 | 12.0 | 21.5 |
| 27989 | Crop | 4 | 97500 | 129500 | 13.0 | 27.5 |
| | | 5 | 95000 | 126000 | 14.0 | 28.0 |
| | | 6 | 102000 | 132500 | 13.0 | 20.5 |
| | | 7 | 88000 | 122000 | 12.0 | 23.5 |
| | | 8 | 92500 | 125000 | 13.0 | 20.5 |
| | | 1 | 92000 | 130000 | 14.5 | 26.5 |
| | A | 2 | 90000 | 125000 | 15.5 | 30.0 |
| | Rail | 3 | 97250 | 127000 | 5.0 | 8.0 |
| | (Mid | 4 | 90000 | 138000 | 9.0 | 10.0 |
| 27989 | Section) | 5 | 92500 | 130000 | 14.5 | 25.0 |
| | | 6 | 90000 | 126000 | 15.0 | 30.5 |
| | | 7 | 85000 | 124800 | 14.0 | 26.5 |
| | | 8 | 95000 | 127500 | 14.5 | 29.0 |
| | | 1 | 90500 | 123000 | 11.5 | 16.0 |
| | | 2 | 85000 | 120000 | 11.5 | 18.0 |
| | | 3 | 90500 | 117000 | 11.0 | 16.0 |
| 27993 | A | 4 | 96000 | 121000 | 13.0 | 20.5 |
| | Crop | 5 | 82500 | 118000 | 13.0 | 26.5 |
| | | 6 | 90000 | 125000 | 11.0 | 17.0 |
| | | 7 | 85000 | 122000 | 10.0 | 15.5 |
| | | 8 | 85000 | 125000 | 10.0 | 17.0 |
| | | 1 | 80000 | 118000 | 13.0 | 22.0 |
| | | 2 | 90000 | 126000 | 12.5 | 24.5 |
| | A | 3 | 87500 | 125000 | 11.5 | 17.0 |
| | Rail | 4 | 80000 | 123000 | 14.0 | 23.0 |
| 27993 | (Mid | 5 | 85000 | 125500 | 12.0 | 17.5 |
| | Section) | 6 | 85000 | 125000 | 13.5 | 24.5 |
| | | 7 | 80500 | 122500 | 13.5 | 20.5 |
| | | 8 | 80000 | 123000 | 14.0 | 27.0 |

## TENSILE TESTS—Continued.

### CARBON RAILS

| Heat No. | Rail | Test No. | Elastic Limit lbs. per sq. in. | Tensile Strength lbs. per sq. in. | Elongation in 2 in. per cent. | Reduction of Area per cent. |
|---|---|---|---|---|---|---|
| | | 1 | 63000 | 112500 | 13.5 | 20.5 |
| | | 2 | 66000 | 114000 | 13.0 | 18.5 |
| | | 3 | 65000 | 114000 | 9.0 | 11.0 |
| | | 4 | 66000 | 114500 | 12.5 | 20.0 |
| | A | 5 | 65000 | 115000 | 12.5 | 17.0 |
| | | 6 | 65500 | 117000 | 11.5 | 17.0 |
| | | 7 | 65000 | 115000 | 12.5 | 16.0 |
| | | 8 | 70000 | 120000 | 12.5 | 18.5 |
| | | 1 | 60000 | 123000 | 10.5 | 14.5 |
| | | 2 | 46000 | 119000 | 10.0 | 17.0 |
| | | 3 | 65000 | 126000 | 9.0 | 11.5 |
| | | 4 | 72250 | 125000 | 9.0 | 13.5 |
| | B | 5 | 75000 | 125500 | 10.0 | 16.0 |
| | | 6 | 70000 | 121000 | 10.5 | 15.0 |
| | | 7 | 57000 | 121000 | 8.5 | 13.5 |
| | | 8 | 80000 | 124500 | 10.5 | 16.0 |

These tests show a decided increase in elastic limit, or useful strength, in favor of the lower carbon vanadium steel, without sacrifice of ductility.

## BEND AND ALTERNATING IMPACT TESTS

The bend tests were made on rectangular pieces about 8 inches long. The load was applied 6 inches from the fixed end of the test piece. The radius of the jaws holding the bend specimen was not over ⅛ inch, and the edges of the specimens were not rounded.

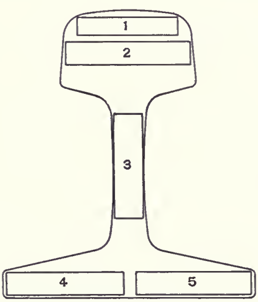


**Fig. 3**

**FIG. 3: Location of Bend Tests.**

**FIG. 4: Location of Alternating Impact Tests.**

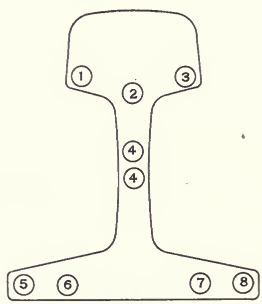


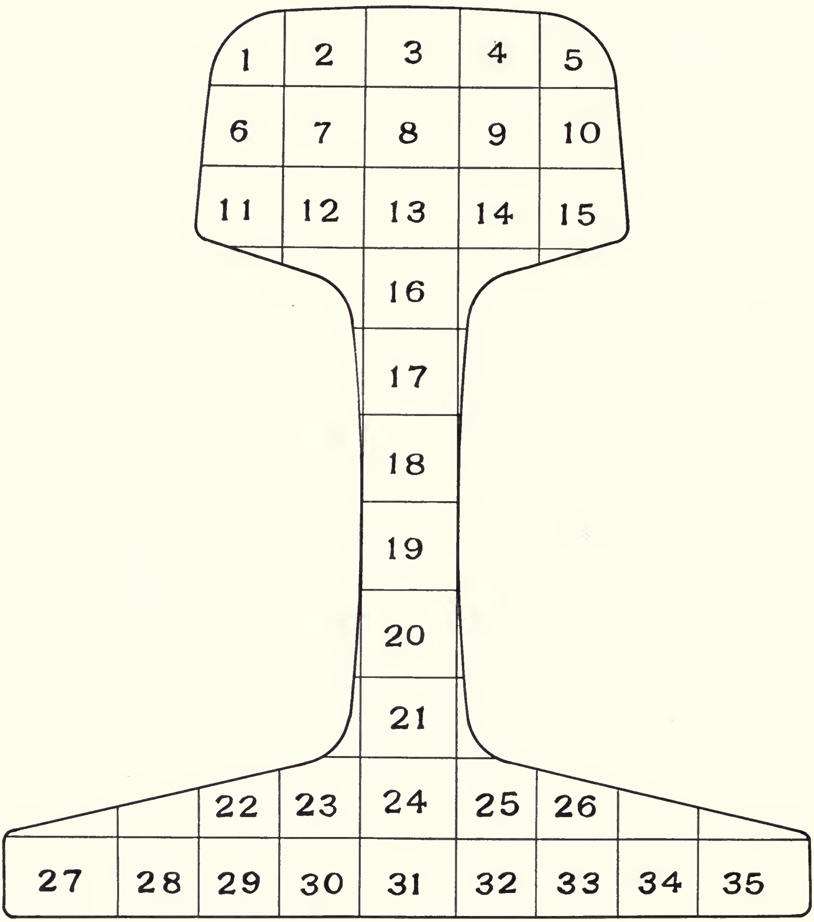
**Fig. 4**

The alternating impact tests are made on bars turned to ⅜ inch diameter. The bar is held firmly in a vise, and the upper end moved backwards and forwards by means of a slotted arm, through a total distance of ¾ inch at the rate of 600 movements per minute. The distance from the vise to the slotted arm is 4 inches. Each movement is accompanied by a blow on the bar by the slotted arm.

| BEND TESTS | | | | | ALTERNATING IMPACT TESTS | |
|---|---|---|---|---|---|---|
| Heat No. | Rail | Test No. | Size | Degrees | Test No. | Alt. Impacts |
| | | 1 | 2.125 x .375 | 50 | 1 | 1464 |
| 26813 Vanadium | A Crop | 3 | 2.0 x .496 | 31 | 2 | 520 |
| | | 4 | 2.4 x .455 | 42 | 3 | 1304 |
| | | 5 | 2.4 x .455 | 49 | 5 | 670 |
| | | | | | 6 | 1600 |
| | | 1 | 2.0 x .300 | 62 | 1 | 1444 |
| | | 2 | 2.4 x .287 | 21 | 2 | 1110 |
| 26813 Vanadium | B Crop | 3 | 2.1 x .533 | 29 | 3 | 1136 |
| | | 4 | 2.3 x .503 | 35 | 4 | 1268 |
| | | 5 | 2.3 x .503 | 40 | 5 | 1454 |
| | | | | | 6 | 1540 |
| | | | | | 7 | 1326 |
| | | | | | 8 | 1580 |
| | | 1 | 2.05 x .30 | 62 | 1 | 960 |
| | | 2 | 2.5 x .35 | 26 | 2 | 790 |
| 27989 Vanadium | A Crop | 3 | 2.05 x .55 | 55 | 3 | 964 |
| | | 4 | 2.2 x .50 | 51 | 4 | 880 |
| | | 5 | 2.45 x .50 | 39 | 5 | 1210 |
| | | 1 | 1.8 x .20 | 61 | 1 | 910 |
| | | 2 | 2.5 x .36 | 55 | 2 | 530 |
| 27993 Vanadium | A Crop | 3 | 2.0 x .55 | 61 | 3 | 800 |
| | | 4 | 2.5 x .50 | 48 | 4 | 784 |
| | | 5 | 2.2 x .50 | 52 | 5 | 1110 |
| | | 1 | 1.9 x .30 | 82 | 1 | 1441 |
| | | 2 | 2.5 x .32 | 39 | 2 | 1250 |
| Carbon | A | 3 | 2.05 x .50 | 57 | 3 | 1716 |
| | | 4 | 2.3 x .50 | 44 | 4 | 1820 |
| | | 5 | 2.45 x .50 | 58 | 5 | 1300 |
| | | 1 | 2.0 x .365 | 47 | 1 | 1208 |
| | | 2 | 2.0 x .275 | 58 | 2 | 980 |
| Carbon | B | 3 | 2.1 x .506 | 47 | 3 | 1670 |
| | | 4 | 2.3 x .502 | 41 | 4 | 1476 |
| | | 5 | 2.3 x .502 | 40 | 4 | 1230 |
| | | | | | 5 | 1604 |
| | | | | | 6 | 1420 |
| | | | | | 8 | 1440 |

## HARDNESS TESTS

Hardness tests were made by the Brinell method. This method of determining hardness consists of measuring the impression made by a standard steel ball under a standard load. The tests were made on sections from the same rail crops from which the other tests were made. The locations of the tests are shown in the accompanying illustration; and the results are given in the following table.




LOCATION OF HARDNESS TESTS

The sections from heat 26813 showed an average hardness of about 340; heat 27989 about 302; heat 27993 about 293; carbon rail "A" about 248, and carbon rail "B" about 269.

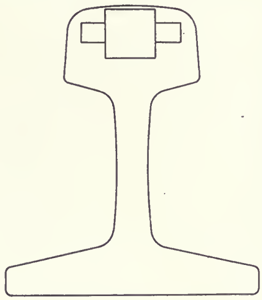
The vanadium steel rails, although lower in carbon, have greater hardness; and hence can confidently be expected to give correspondingly increased resistance to wear in the track.

## HARDNESS TESTS

| VANADIUM RAILS | | | | | CARBON RAILS | |
|---|---|---|---|---|---|---|
| Serial No. | Rail 26813-A | Rail 26813-B | Rail 27989-A | Rail 27993-A | Rail A | Rail B |
| 1 | 302 | 340 | 286 | 286 | 241 | 269 |
| 2 | 340 | 340 | 302 | 286 | 235 | 269 |
| 3 | 340 | 340 | 302 | 286 | 248 | 262 |
| 4 | 340 | 340 | 293 | 286 | 241 | 269 |
| 5 | 311 | 340 | 286 | 286 | 228 | 255 |
| 6 | 340 | 340 | 302 | 293 | 248 | 269 |
| 7 | 340 | 340 | 307 | 302 | 255 | 269 |
| 8 | 340 | 340 | 307 | 302 | 241 | 269 |
| 9 | 340 | 340 | 307 | 302 | 241 | 262 |
| 10 | 340 | 340 | 302 | 293 | 241 | 269 |
| 11 | 340 | 340 | 302 | 293 | 241 | 269 |
| 12 | 340 | 340 | 307 | 302 | 262 | 269 |
| 13 | 364 | 340 | 311 | 302 | 255 | 293 |
| 14 | 340 | 340 | 307 | 302 | 255 | 269 |
| 15 | 340 | 340 | 307 | 269 | 217 | 269 |
| 16 | 387 | 340 | 302 | 293 | 241 | 302 |
| 17 | 387 | 340 | 293 | 293 | 248 | 302 |
| 18 | 364 | 340 | 302 | 286 | 248 | 302 |
| 19 | 364 | 340 | 302 | 293 | 248 | 302 |
| 20 | 364 | 332 | 293 | 293 | 248 | 302 |
| 21 | 364 | 332 | 293 | 302 | 248 | 302 |
| 22 | 340 | 332 | 311 | 311 | 269 | 269 |
| 23 | 340 | 340 | 311 | 311 | 269 | 269 |
| 24 | 340 | 340 | 302 | 307 | 269 | 286 |
| 25 | 340 | 332 | 311 | 286 | 255 | 269 |
| 26 | 340 | 340 | 311 | 293 | 255 | 269 |
| 27 | 321 | 340 | 311 | 302 | 262 | 269 |
| 28 | 321 | 332 | 302 | 311 | 269 | 269 |
| 29 | 321 | 332 | 311 | 311 | 255 | 269 |
| 30 | 340 | 332 | 311 | 307 | 248 | 269 |
| 31 | 340 | 332 | 302 | 307 | 241 | 269 |
| 32 | 340 | 332 | 311 | 302 | 228 | 269 |
| 33 | 332 | 340 | 311 | 302 | 241 | 269 |
| 34 | 332 | 340 | 307 | 302 | 269 | 269 |
| 35 | 332 | 340 | 293 | 302 | 255 | 269 |

## WEAR TESTS

This test is made by rotating a piece 1 in. long by 1 in. diameter between three manganese steel rollers of 3 in. diameter. The two bottom rollers are driven by gears with a different number of teeth; which gives the rollers different speeds and causes the test piece to slip as well as rotate, imitating the action of a car wheel on the rail. The tests were all taken from the head as shown in the illustration.



**Location of Wear Tests**

A direct load of 110 lbs. is applied to the test piece by loading the top roller. In previous tests, a load of 220 lbs. was used. Owing to the great tendency of soft rails like carbon rail "A" to flow and form a fin or bead which gave trouble, the weight was reduced to 110 lbs. It was found that the abrasion of the test piece was better with this weight than with the heavier load. The test pieces were weighed before and after test. The loss in weight in millegrams was divided by the original weight of the test piece; in order to obtain comparative figures and allow for variations in weight of test pieces. The tests which follow were all run 50,000 revolutions:

| Heat | Rail | Milligrams Loss Divided by Weight of Test | Relative Wear |
|---|---|---|---|
| 26813 | A–Crop | 16.3 | 54 |
| 26813 | B–Crop | 13.1 | 45 |
| 27989 | A–Crop | 12.8 | 44 |
| 27993 | A–Crop | 12.2 | 42 |
| Carbon | A | 28.8 | 100 |
| Carbon | B | 21.1 | 73 |

The relative wear of the vanadium steel rails is practically one-half that of the carbon rails.

## CHEMICAL ANALYSES OF RAIL SECTIONS FREEDOM FROM SEGREGATION

Chemical analyses were made of rails from each of the vanadium heats; to determine whether there was any tendency to segregation, and how the vanadium steel compared in this respect with the carbon steel. For this purpose, drillings were taken from two locations in the head of the rail. One sample was taken from the top corner of the head, corresponding to the outer portion of the ingot; and the other sample was taken from the junction of the head with the web, corresponding to the axial center of the ingot where any segregation present would be most certain to be found.

There is no segregation in the case of the vanadium steel rails, the results all being within the limit of analytical error. In the case of the vanadium rails, all the samples were taken from rail crops.

## CHEMICAL ANALYSES

| Heat No. | Rail | Location of Sample | Carbon Per Cent. | Manganese Per Cent. | Phosphorus Per Cent. | Sulphur Per Cent. | Vanadium Per Cent. |
|---|---|---|---|---|---|---|---|
| 26813 | A | Corner of Head | .55 | 1.49 | .015 | .023 | .147 |
| | | Top of Web | .56 | 1.52 | .015 | .022 | .148 |
| 26813 | B | Corner of Head | .54 | 1.46 | .016 | .022 | .144 |
| | | Top of Web | .57 | 1.49 | .017 | .021 | .147 |
| 27989 | A | Corner of Head | .52 | 1.11 | .013 | .022 | .150 |
| | | Top of Web | .52 | 1.11 | .013 | .024 | .150 |
| 27993 | A | Corner of Head | .56 | .73 | .019 | .023 | .158 |
| | | Top of Web | .57 | .74 | .019 | .024 | .159 |
| Carbon | A | Corner of Head | .72 | .67 | .035 | .028 | |
| | | Top of Web | .79 | .68 | .047 | .038 | |
| Carbon | B | Corner of Head | .74 | .68 | .011 | .035 | |
| | | Top of Web | .81 | .69 | .012 | .041 | |

## HOMOGENEITY AND DENSITY (ETCHED SECTIONS)

Sections from the rails tested were polished and etched in boiling dilute sulphuric acid and photographed.

The time required for etching the vanadium steel rail sections was several times longer than for the carbon rails. The average time required was about 30 minutes, as against 5 minutes for the "A" carbon steel rail and about 15 minutes for the "B" carbon steel rail. The difference in length of time of etching is also a very good indication of the comparative resistance to wear.

## CONCLUSIONS

From the results of the tests made on these three heats, the American Vanadium Company recommend for vanadium steel rails the chemical specification given on the following page.

This specification will give rails with 30% to 50% higher elastic limit, or useful strength, combined with greater toughness and hardness than simple carbon steel rails with .62% to .75% carbon content. The vanadium steel rails will show even greater superiority in comparison with lower carbon steel rails of .45% to .60% carbon.

| | |
|---|---|
| Carbon | .45 to .60% |
| Manganese | 1.00 to 1.25% |
| Silicon | over .10% |
| Phosphorus | not over .05% |
| Sulphur | not over .05% |
| Vanadium | 4 lbs. added per gross ton |

The relatively low percentage of carbon recommended, together with the great freedom from segregation of vanadium steel, should result in the practical elimination of the danger of failure from internal fissures, silvery oval spots.

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